**Transportation Literature Search**
RESEARCH & LIBRARY SERVICES
research@dot.wi.gov
library@dot.wi.gov

# Differences between Plastic and Hardened Air Measurements in Placed Concrete, and Effects of Mix Design and Paver (Including Influence on Air Void Size and Distribution)

*Prepared for*
**WHRP Rigid Pavements Technical Oversight Committee**

*Prepared by*
**CTC & Associates LLC**
**WisDOT Research & Library Unit**

**November 23, 2009**

*Transportation Literature Searches are prepared for WisDOT staff and investigators to identify completed research and other authoritative information in an area of interest. The citations below are representative, rather than exhaustive, of available English-language studies on the topic. Primary online resources for the literature searches are OCLC's WorldCat and TLCat, U.S. DOT's TRIS Online, the National Transportation Library (NTL), TRB's Research in Progress (RiP) database, and other academic, engineering and scientific databases as appropriate.*

*To request a literature search, contact the WisDOT Library at library@dot.wi.gov or (608) 264-8142, or WisDOT Research at research@dot.wi.gov or (608) 267-6977.*

**Keywords**: air entrainment, entrained air, air entraining, in-place mix air content, air-void, quality of air-void, plastic and hardened air measurement, loss of hardened air content, loss of hardened entrainment, loss of entrained air, loss of air in plastic concrete, loss of air in hardened concrete, maintain air content concrete, effect of paver on air content, effect of paver on entrained air, effect of paver on air, air content stability, air void stability.

## Summary

We found 11 citations for documents published in 1999 or later, and four Research in Progress entries. Two of the citations were published in 2009, one each in 2008, 2006, 2005 and 2004, two each in 2003 and 2002, and one in 1999. Two of these reports refer to state DOT studies.

## Citations

*Links to online copies of cited literature are provided when available. Contact the WisDOT Library to obtain hard copies of citations.*

**Title: Investigations on the Influence of Fly Ash on the Formation and Stability of Artificially Entrained Air Voids in Concrete**
**Author(s):** Spörel, F.; Uebachs, S.; Brameshuber, W.
**Date:** March 2009
**Source/URL:** *Materials and Structures*, Vol. 42, No. 1, pages 227-240.
**Description:** 14 pages
**Contents:** In concrete, fly ash is applied to a task-oriented improvement of different properties. Besides the advantages, e.g., the improvement of the rheology of the fresh concrete or the density of the hardened concrete, some investigations and the experience from practice indicate that some fly ashes probably influence the formation and stability of artificially entrained air voids. The reason lies presumably in the fraction of unburned carbon, a minor component of the fly ash. To identify the causes, seven fly ashes from European power plants were investigated. The fly ashes were characterized and mortar and concrete tests were conducted to identify specific fly

ash parameters which might be responsible for the impaired formation and stability of the air voids. Furthermore, it was examined whether the foam index test is applicable for the assessment of the air entraining agent demand and whether an adequate accuracy of the results is given. On the basis of the results it was also examined whether the mortar tests or a fly ash specific parameter can be applied as an alternative prediction tool to assess the air entraining agent demand for an air entrained concrete.

**Title: Monitoring the Liquid to Solid Transition in Concrete with Conventional Tests**
**Author(s):** Abel, J.; Pinto, R. C. A.; Hover, K. C.
**Date:** 2009
**Source/URL:** Conference Proceeding Paper from Transition from Fluid to Solid: Re-Examining the Behavior of Concrete at Early Ages
**Description:** 16 pages
**Contents:** This paper describes how a simple but challenging experiment was carried out to measure concrete temperature, air content, unit weight, slump, setting (penetration resistance), heat release, maturity, and compression strength. The experiment spanned a 28-day period beginning with discharge from the chute of a concrete truck. It was thus demonstrated that concrete's transition from liquid to solid is represented continuously by maturity and by heat release, but it is more commonly recorded in terms of three phases in concrete development: slump loss, setting, and strength gain. The paper describes how these phases overlap each other and are related to concrete temperature, heat release, and maturity.

**Title: Observations of Air-Bubbles Escaped from Fresh Cement Paste**
**Author(s):** Ley, M. Tyler; Folliard, Kevin J.; Hover, Kenneth C.
**Date:** 2008
**Source/URL:** *Cement and Concrete Research*, Vol. 39, No. 5, May 2009, pages 409-416.
**Description:** 8 pages
**Contents:** Recent experimental work is presented using a new technique to observe bubbles that have escaped from cement pastes and suspended in the bleed water. These experiments suggest that the stability of an air-entrained bubble may be related to the integrity of the hydration shell. This paper also reviews literature dealing with changes to air bubbles with time in fresh air entrained cement paste and concrete and to the existence of a shell surrounding these bubbles.

**Title: Air-Void Stability in Fresh Self-Consolidating Concretes Incorporating Rice Husk Ash**
**Author(s):** Safiuddin, Md.; FitzGerald, G. R.; West, J. S.; Soudki, K. A.
**Date:** 2006
**Source/URL:** *Advances in Engineering Structures, Mechanics & Construction*, Vol. 140, pages 129-138.
**Description:** 10 pages
**Contents:** This paper presents the results of experimental study on air-void stability in fresh self-consolidating concretes. Two series of self-consolidating concrete were undertaken for conducting laboratory tests. Each series of concrete included three different fresh mixtures. The air-void stability in fresh concretes was investigated with respect to post-mixing and agitation. The air content of fresh concretes was determined at various test stages and adjusted considering aggregate correction factors. The flowing ability of the fresh concretes was also examined with regard to slump and slump flow. The entire testing period involved four stages extended to 60 and 90 minutes for series 1 and 2, respectively. Test results reveal that the slump and slump flow of the concrete mixtures were consistent in all test stages, and the loss of air content was minimal. The maximum loss of air content over the period of 60 and 90 minutes was less than 1.0 percent. Rice husk ash did not affect the air-void stability in fresh concretes. However, it increased the demand for high-range water reducer and air-entraining admixture. The overall test results indicate that the air-void stability in all fresh self-consolidating concretes was satisfactory.

**Title: Mechanisms of Air Entrainment in Concrete**
**Author(s):** Du, Lianxiang; Folliard, Kevin J.
**Date:** August 2005
**Source/URL:** *Cement and Concrete Research*, Vol. 35, No. 8, pages 1463-1471.
**Description:** 9 pages
**Contents:** The advent of air-entraining agents is probably one of the most important technological advances in construction in the last century. It has been widely used to improve the freeze-thaw resistance of concrete, and to a lesser extent, the workability of concrete. Despite the overall successful application of air-entraining agents in concrete, problems in field concrete are not uncommon. The ability to consistently obtain target air-void systems in concrete is not trivial, and changes in raw materials, processing, or construction methods may significantly impact air entrainment. To address these potential problems in the field, a sound understanding of the mechanisms of air

entrainment is essential. This paper attempts to synthesize available literature and field experience and provide a framework for understanding the fundamental aspects of air entrainment in concrete. Various parameters and influencing factors, such as concrete temperature, the physical and chemical characteristics of constituent materials, and mixing and placing techniques, are discussed.

**Title: Are We Placing Too Much Air in Our Concrete? Today's More Effective Air Entraining Agents are Specified the Same as They were 50 Years Ago**
**Author(s):** Nasvik, Joe; Pistilli, Mike
**Date:** February 2004
**Source/URL:** *Concrete Construction*,
http://findarticles.com/p/articles/mi_m0NSX/is_2_49/ai_113855231/?tag=content;col1
**Description:** N/A
**Contents:** About 15 years ago there was a shortage of Vinsol Resin, so admixture manufacturers developed new materials. Generally speaking, these newer air-entraining admixtures create smaller bubbles that are spaced more closely together. This means that less total air is needed to achieve the necessary resistance to freeze-thaw cycles. Industry guidelines regarding air-entrainment requirements, however, are still based on using Vinsol Resins and haven't changed in over 50 years. There is little mention of newer products or technology, which now account for more than half the AEA used today. Because these newer admixtures can be much more effective, often more than the required amount of air is entrained into the concrete than is needed for protection.

**Title: Frost Resistance of Hardened Concrete**
**Author(s):** Okkenhaug, K.; Gjorv, O. E.
**Date:** September 2003
**Source/URL:** *Concrete International*, Vol. 25, No. 9, pages 49-54.
**Description:** 6 pages
**Contents:** An assessment of air-void characteristics is often used to test the potential frost resistance of hardened concrete. This study, part of a larger research program on maintaining an air-void system during concrete construction, investigates the effects of fine aggregate on concrete's air-void system. Three different sources of natural fine aggregate were used in three test series. For all concrete mixes, the aggregate and cement were dry-mixed and then water was added. The air-entraining admixture was added after 120 s of mixing and then the total air content was measured after 75, 150 and 450 s of further mixing. The stability of the air-void system was tested by subjecting the pressure meter to vibration. During vibration, the loss of air was determined without any pressure during a period of 180 s. After vibration, the total air content was determined and the intermittent readings were recalculated. From each batch, a concrete cube was cast for analysis of the air-void system in the hardened concrete. For hardened concrete analysis, specimens were prepared based on a modified point-count method. Findings showed that the use of different sources of fine aggregate may produce very different air-void systems in concrete. The source of sand that produced the lowest total air content also produced the best air-void system. The shape of the grading curve, the amount of filler (and hence the packing of the fine aggregate particles) and the total amount of fine aggregate also appeared to be important parameters for the development of the air-void system.

**Title: Air-Entraining Admixtures for Use with Fly Ashes Having High Carbon Contents**
**Author(s):** Nkinamubanzi, P. C.; Bilodeau, A.; Jolicoeur, C.; Golden, D. M.
**Date:** 2003
**Source/URL:** Conference Proceeding Paper from Seventh CANMET/ACI International Conference on Superplasticizers and Other Chemical Admixtures in Concrete, pages 543-572.
**Description:** 30 pages
**Contents:** The objective of this study was to evaluate the potential use of a series of new air-entraining admixtures in concrete incorporating fly ashes with a high carbon content. After many tests on mortars and concrete, adjustments were made by the producer on the most promising admixture to finally obtain an admixture as suitable as possible for use in concrete incorporating fly ash with a high carbon content. The final product (NDb) showed real potential in producing adequate air content in fresh concrete and a very good air void system in the hardened concrete. The differences in the air content of the fresh and the hardened concrete is not high, which indicates a good stability of the air entrained. The new air-entraining admixture is less sensitive to the over-dosage compared to the reference product, which is interesting from a practical point of view for concrete producers. All properties of fresh concrete evaluated with the mechanical properties of the hardened concrete are similar for the new admixture and the reference. There is still no effect to use the admixture in concrete, even the fly ash content of the concrete is as high as 55 percent. The resistance to chloride ions penetration and the frost-resistance of concrete made with this

new admixture are excellent. The only problem remaining to solve is the poor compatibility of this new admixture with polysulfonate-based high-range water reducing admixtures. However, the compatibility with acrylic-based water-reducing agents is very good.

**Title: Research Pays Off: Vibrator Monitors: Concrete Paving Technology Generates Buzz**
**Author(s):** Steffes, R.; Tymkowicz, S.
**Date:** November 2002
**Source/URL:** *TR News* (Transportation Research Board), No. 223, pages 19-20.
**Description:** 2 pages
**Contents:** The Iowa Department of Transportation specified use of vibrator monitors on paving machines in 1999, and current specifications require the use of vibrator monitors on pavers for projects of 50,000 sq. yd. or more. Use of monitors has provided appropriate control of vibrators and has eliminated trails of segregated, low-air content, deterioration-prone concrete. The vibrator monitors record and display data such as vibrator frequency, paver location, travel speed, and air temperature for all vibrators at all times. The vibrator monitors improve portland concrete cement pavement quality and reduce deterioration, while reducing maintenance time and costs.

**Title: Low w/cm Ratio, VMAs Drive SCC Air-Void Stability**
**Author(s):** Concrete Products Staff
**Date:** November 2002
**Source/URL:** *Concrete Products*, November 1, 2002.
**Description:** N/A
**Contents:** University of Sherbrooke (Quebec) Civil Engineering Department researchers find that greater air void stability can be realized in self-compacting concrete when the mix design contains a high proportion of cementitious materials and lower water-to-cementitious materials ratio. In an *ACI Materials Journal* report, Professor Kamal Khayat and PhD candidate Joseph Assaad note that the increasing use of SCC and other highly flowable mixes raises the issue of securing proper air-void system during mix agitation, placement and setting. In "Air-Void Stability in Self-Consolidating Concrete," they outline testing of a group of specimen mixes with high and low w/cm ratio, varying dosages of performance pozzolans, and air-entraining and viscosity-modifying admixtures.

**Title: Vibration Study for Consolidation of Portland Cement Concrete**
**Author(s):** Tymkowicz, S.; Steffes, R.
**Date:** March 1999
**Source/URL:** Report from Iowa Department of Transportation
**Description:** 104 pages
**Contents:** The Iowa Department of Transportation has noticed an increase in the occurrence of excessively vibrated portland cement concrete pavements. The overconsolidation of PCC pavements can be observed in several sections of PCC highways across the state of Iowa. Also, excessive vibration is believed to be a factor in the premature deterioration of several pavements in Iowa. To address the problem of excessive vibration, a research project was conducted to document the vibratory practices of PCC slipform paving in Iowa and determine the effect of vibration on the air content of pavement. The primary factors studied were paver speed, vibrator frequency, and air content relative to the location of the vibrator. The study concluded that the Iowa Department of Transportation specification of 5000 and 8000 vibrations per minute (vpm) for slipform pavers is effective for normal paver speeds observed on the three test paving projects. Excessive vibration was clearly identified on one project where a vibrator frequency was found to be 12,000 vpm. When the paver speed was reduced to half the normal speed, hard air contents indicated that excessive vibration was beginning to occur in the localized area immediately surrounding the vibrator at a frequency of 8000 vpm. Analysis of variance testing indicated many variables and interactions to be significant at a 95 percent confidence level; however, the variables and interactions that were found to be significant varied from project to project. This affirms the complexity of the process for consolidating PCC.

## Research in Progress

**Title: Development of a Robust Field Technique to Quantify the Air-Void Distribution in Fresh Concrete**
**Principal Investigator(s):** Ley, Tyler, Oklahoma State University, tyler.ley@okstate.edu
**Start Date:** June 2009
**RIP URL:** http://rip.trb.org/browse/dproject.asp?n=22761
**Sponsor Organization:** Oklahoma Department of Transportation
**Contents:** The over 6 billion cubic meters of concrete produced annually can suffer frost damage when subjected to moisture and freezing temperatures. Frost-durable concrete can be produced if a specialized surfactant (also known

as an air-entraining admixture) is added during mixing to stabilize microscopic air voids. Small and well-dispersed air voids are critical to produce frost-resistant concrete. Currently, no reliable and repeatable method exists to measure the size and distribution of air voids in fresh concrete. Instead, construction specifications require a total volume of air in a concrete mixture to provide frost durability. Although, total volume of air is a widely used standard in the concrete industry it does not always accurately predict frost resistance. This is usually attributed to inaccuracies with current measurement techniques, the inability of the current techniques to quantify the spacing and distribution of the air voids, or a change in the properties of the air-void system from the moment measured to when the concrete hardens. Due to these challenges the quality control of air-entrained concrete was recently named as a major challenge to the concrete industry. There is a need for more precise and robust techniques to measure the size and distribution of air voids in fresh concrete as well as more knowledge of how the air-void system changes over time. Preliminary data by the research team indicates that compacted concrete with the same total volume of air but with different void sizes and distribution show dissimilar volume changes to increases in pressure. This observation suggests that equipment already used to measure the air volume in concrete by using the volume change of the material from a single pressure change could be modified to use multiple pressure changes to measure the air-void distribution. Although the total volume of concrete changes with pressure, it is not understood how the change in individual air voids contribute to this volume change. After a technique is established to quantify the void system in fresh concrete, work is still needed to predict if the void system will change with time. Published results from the PI in refereed journal articles indicate that the properties of the air-void wall determine resistance to gas transfer from the surrounding fluid and therefore size change. Recent measurement techniques have been developed at Oklahoma State University to use micro computed tomography (ìCT) to observe the in-situ 3D air-void system in fresh or hardened concrete. This new technique will allow single air-entrained bubbles to be observed and how they respond to pressure changes or if they change size with time. The central hypothesis of this proposal is that the use of ìCT in combination with an evaluation of the chemical and physical properties of the air-void wall will allow a new understanding of how different size air-voids respond to pressure and if the air-void system will change in volume with time. The specific aims for this project are: (1) Determine the correlation between the volume change of individual air-entrained voids and the surrounding fluid pressure through observations made with an ìCT scanner. (2) Investigate the impact of pressure increases on the bulk volume change of the air-void system. (3) Develop a procedure to use existing concrete quality control equipment and multiple pressure changes to estimate the air-void distribution in fresh concrete. (4) Determine the characteristics of an air-void wall that affect the change in the air-void size with time and how mixture ingredients influence these characteristics. By completing this research a technique will be created that satisfies a great need in the transportation industry and directly addresses the strategic plan of the Oklahoma Transportation Center.

**Title: Technology Evaluation on Characterization of the Air Void System in Concrete**
**Principal Investigator(s):** Lopez, Maria, Pennsylvania Department of Transportation, (814) 865-9423
**Start Date:** July 2008
**RIP URL:** http://rip.trb.org/browse/dproject.asp?n=19499
**Sponsor Organization:** Pennsylvania Department of Transportation
**Contents:** In addition to winter conditions in Pennsylvania, deficient material quality, among other factors, can severely affect the durability of concrete pavements, thus diminishing their service life. A common and well-proven quality control measure has been the determination of air content in fresh concrete (using ASTM standard test methods such as ASTM C231, C173 and C138). More reliable indicators of future performance can be obtained from hardened concrete by analyzing the air void system, in particular the air content, spacing factor and specific surface (ASTM C457). The need for obtaining these parameters at the fresh state of concrete, thus significantly improving the quality control of concrete pavements at an early stage, has moved research in universities and industry to investigate technologies that can characterize the air void system. A recently completed project by the Pennsylvania Department of Transportation (PennDOT) evaluated the effectiveness of a commercially available device (Air Void Analyzer) to characterize the distribution of air voids in fresh concrete. This device was found not ready for field-based applications (PennDOT/MAUTC Work Order No. 6, 2007). The objective of this project is to evaluate current technologies that have the capability of characterizing the air void system in concrete within the first several hours of placement. This objective will be met by conducting a review of current research developments at universities, research centers, and industry facilities that have the potential for characterizing concrete air void system parameters such as air content, spacing factors and surface areas and assessing their feasibility. This evaluation will specifically focus on technologies that have the potential of being implemented in the field.

**Title: Entrained Air Void System in Concrete Structure and Pavements**
**Principal Investigator(s):** None listed
**Start Date:** May 2006
**RIP URL:** http://rip.trb.org/browse/dproject.asp?n=12365
**Sponsor Organization:** University of Kentucky
**Additional Information:** This appears to be the same project described in Kentucky Transportation Center's 2008 research program summary http://www.ktc.uky.edu/PDF/researchbriefFY08.pdf, page 4, "Maintaining an Adequate Air Voids System for PCC (Study #08-363)." The contact is Clark Graves, (859) 257-7388, cgraves@engr.uky.edu.
**Contents:** Entraining air in concrete continues to challenge both specifiers and producers. On the one hand, concrete failures are still being reported due to inadequate air-void systems in transportation structures and pavements subjected to cyclic freezing and thawing in a saturated condition. On the other hand, low compressive strength resulting from excessive air content or excessively close spacing of air voids continues to occur. Both problems reflect the difficulties practitioners are having in achieving a consistent air-void system in in-place works. This is either due to variability in materials or practices, inadequate understanding of the differences in behavior of the various materials that can be used (i.e., air-entraining admixtures), or due to changes in the mixture during processing (i.e., after the batch has been tested and accepted). Furthermore, there is debate with regards to the amount of air and the required characteristics of the air-void system needed for frost resistance for modern concrete, with some questioning whether entrained air is needed at all in high performance mixtures.

**Title: Hardened Air in Concrete Roadway and Structures**
**Principal Investigator(s):** Azab, Alaa (Project Manager), Pennsylvania Department of Transportation, mazab@state.pa.us
**Start Date:** January 2006
**RIP URL:** http://rip.trb.org/browse/dproject.asp?n=17486
**Sponsor Organization:** Pennsylvania Department of Transportation
**Contents:** The measurement of plastic air content at the point of placement is currently used for the acceptance of concrete for placement. This test method provides a means of determining the presence of an adequate quantity of air, but the test is not able to determine the quality of the air void system, e.g., air void size and distribution. The quality of the air void system is determined by the hardened air content evaluation. Under some circumstances, the characteristics of the hardened air do not meet the requirements to ensure that the concrete will resist the damage of freezing and thawing cycles in Pennsylvania. There is a need to review and/or revise the specification for air content acceptance to more reliably obtain concrete that is resistant to freeze-thaw cycles. This research project seeks to (1) determine the state of practice in plastic and hardened air measurement and evaluation for highway applications and (2) resolve the PennDOT hardened air specification with the plastic air specification used for concrete acceptance.